Marine Fuel Cells

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Hyatt Regency Hotel
San Francisco, CA

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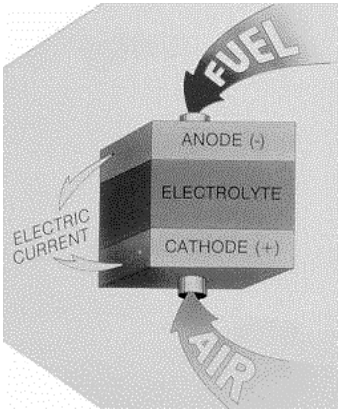
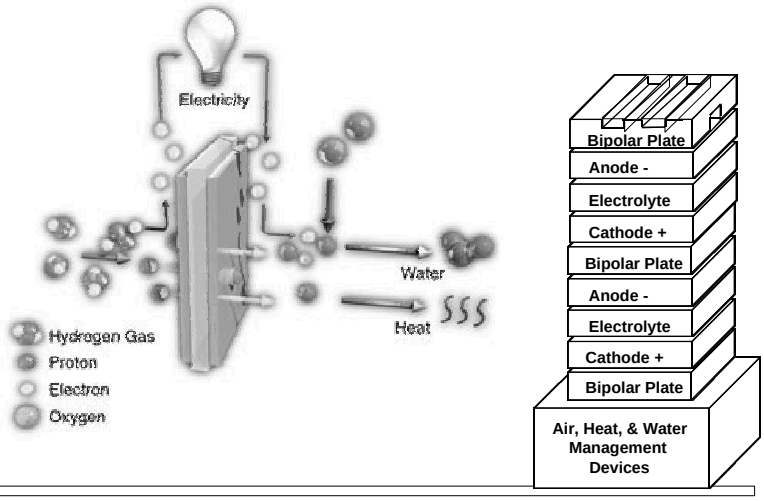
What is a Fuel Cell

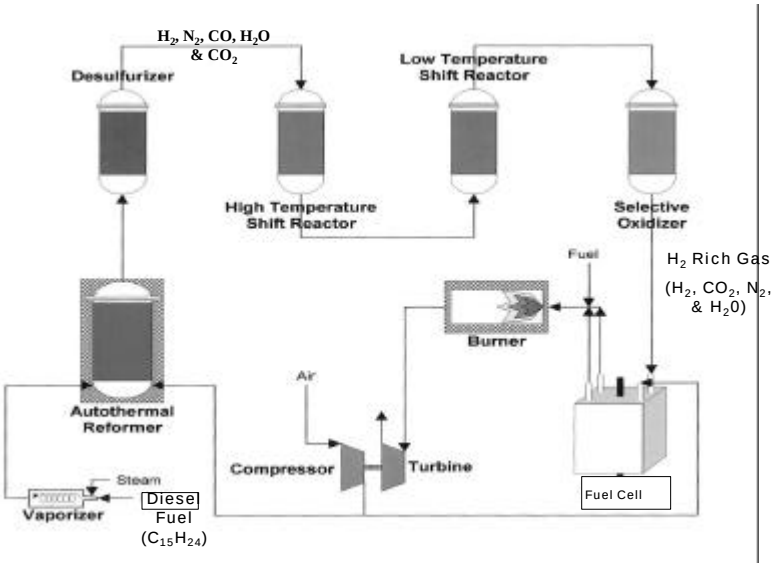
A Fuel Cell operates likes a battery. It supplies electricity by combining hydrogen and oxygen electrochemically without combustion. Unlike a battery, it does not run down or require recharging and will produce electricity, heat and water as long as fuel is supplied.



Fuel Cell Operation



Fuel Reforming



Fuel Cell Types

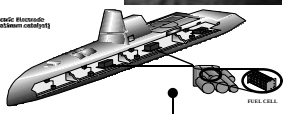
	Electrolyte	Cell Temp (°F)	Lifetime Projected (Hrs)	Cell Contaminant	Single-Cycle Electrical Efficiency (%)
Proton Exchange Membrane (PEM)	Polymer Membrane (Solid)	180	40,000	S, CO	35-40
Alkaline (AFC)	Potassium Hydroxide (Solid)	200	10,000	CO, CO2	<40
Phosphoric Acid (PA)	Phosphoric Acid (Liquid)	450	40,000	S,CO	35-40
Molten Carbonate (MC)	Potassium Lithium Carbonate (Liquid)	1200	40,000	S	45-55
Solid Oxide (SO) [Tubular, planar, monolithic]	Zirconium Dioxide Ceramic (Solid)	1800	40,000	S	45-60

Fuel Cell Manufacturers

	PA	PEM	MC	SOFC
Ballard		X		
DAIS Analytic		X		
Fuel Cell Energy			X	
H Power		X		
Honeywell		X		X
International Fuel Cells	X	X		
Plug Power		X		
Siemens Westinghouse				X
Technology Management Inc				X
Ztek				X

Fuel Cell Markets

Fuel cell power system markets could soon exceed $3 billion worldwide*



UUV/MCM

10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7

Power (Watts)

MEMS

“BA5590”

Home Electricity

UAV

Stationary Power

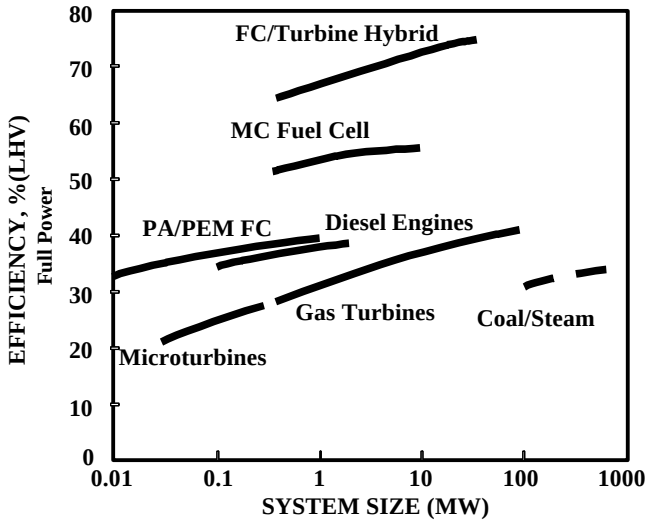
*Arthur D. Little, Inc, Cambridge, MA, reference #44335.

Shipboard Market

- Marine Market Surveys for fuel cell power sources by MTI for PEM systems and FCE for MC systems conclude:
  - Ship Service fuel cell generators for both commercially and Military Marine Markets compete economically with small turbines and marine diesels in terms of life cycle costing.
  - Diesel-fueled fuel cell ship service generator system for commercial marine applications will be in the 200 kW to 1 Mw range; military applications in the 500 kW to 2.5 Mw range.
  - Military represents only 1% of total marine FC market.
- Independent USCG marine market survey validates conclusions.
- DOE/Industry also project future new concept higher power, ultra-high efficiency fuel cell power systems adaptable for marine high power propulsion applications

Diesel-fueled commercial and military surface ship markets represents a significant potential market; circa 2005.

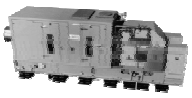
COMPARISON OF EFFICIENCIES FOR ELECTRIC POWER PLANTS



Annual Fuel Consumption

(3,000 Operating Hours)

Gas Turbine Generator Set



641,465 Gallons

$628,636

Diesel Generator Set

321,703 Gallons

$315,268

Fuel Cell Generator Set

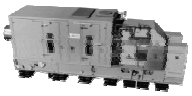
214,315 Gallons

$210,028

= 50,000 gallons; ($.98/gallon)

Annual Maintenance

Gas Turbine Generator Set



1,050 Hrs

Diesel Generator Set

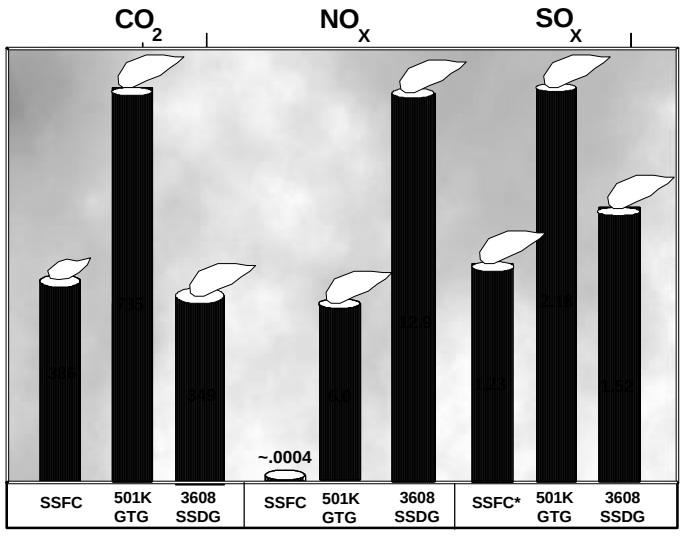
1,031 Hrs

Fuel Cell Generator Set

739 Hrs
(Present Technology)

= 100 hours of maintenance

EMISSION COMPARISON
(gm/HP Hr @ 100% Power)



* With Desulfurizer Regeneration

Fuel Cell Design Comparison

Design Issues	Ships	Cars Trucks	Utility
Power Density	High	High	Low
Fuel Type	Navy Distillate/ Marine Diesel	Gasoline/H2/ Methanol/Diesel	Natural Gas/ Coal Derived
Life, MTBO	40,000 Hrs	10,000 Hrs	40,000 Hrs
Dynamic Response	Fast	Fast	Slow
Operating Environment	Severe	Moderate	Benign

Program Summary

Objective: Develop shipboard fuel cell power systems with acquisition cost, weight, and volume comparable to other market options, for future Navy ships and craft.

State of the Art: Industry is developing fuel cell technology for stationary and non-marine transportation applications operating on non-logistics fuels. Commercial units expected between 2001 and 2005, with stationary systems available before automotive systems. Little effort in diesel reformation.

Approach: Develop fuel cell power systems and components to enable commercial fuel cell equipment to be used in the unique Naval shipboard environment.

Navy Technical Challenges

- Fuel Type
  - ✓ Logistic Fuel reforming
- Power Density, Cost & System Efficiency
- Reliability and Maintainability
- Duty Cycle/Transient Response
- Marine Environment
  - ✓ Cell Life
  - ✓ Environmental Contaminants
  - ✓ Shock & Vibration
  - ✓ Ship Motions

Navy Shipboard Fuel Cell Program

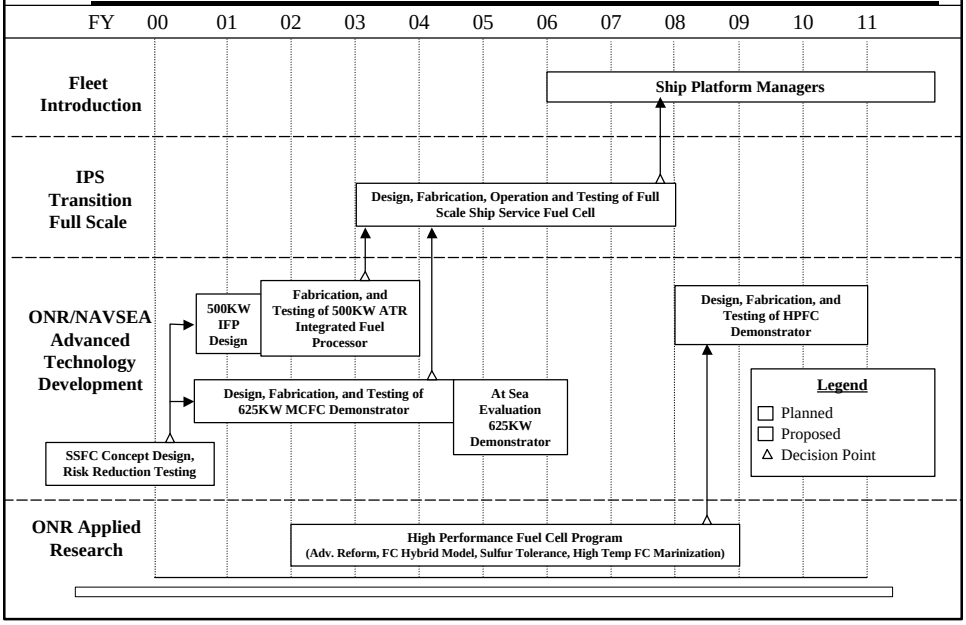
Goals/Metrics

	DDG-51 GTG	AOE-6 SSDG	SSFC Goals *2005*	HPFC Goals *2010*
Unit Volume (ft3/kW)	1.1	2.84	2	TBD
Unit Weight (lb/kW)	27.2	36.4	40	TBD
Fuel Efficiency (at 50% load)	16%	37%	40%	70%
Acquisition Cost ($/kW)	1600	480	1500	1200
Scalable to: (MW)	-	-	3	20

SSFC: Ship Service Fuel Cell Program
HPFC: High Performance Fuel Cell Program

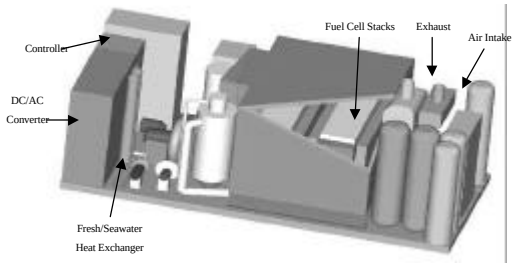
Navy Shipboard Fuel Cell Program

Program Timeline/Transition



Navy Shipboard Fuel Cell Program

Ship Service Fuel Cell Program Demonstration



FuelCell Energy 625kW 450V, 3ϕ , 60 HZ, 50% Efficient MC SSFC Power Module Concept

PHASE I: Complete ($4.6M) FY00

- 2.5 MW SSFC Conceptual Design
- Sub-scale risk reduction demonstrations
  - Cell salt air tolerance
  - NATO F-76 diesel fuel reforming
  - Fuel contaminant removal and cell sensitivity (sulfur)
  - Cell shock and vibration
- Analytical model
- Marine/Navy market surveys

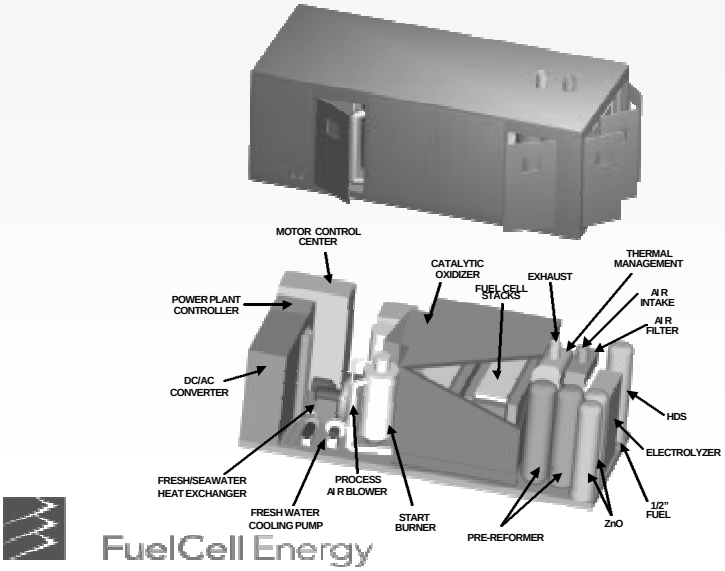
PHASE II: (36 month, $12.6M ONR cost shared contract awarded May 00 to FCE, Inc.)

- 625kW SSFC module detailed design
- 625kW SSFC module fabrication
- Factory testing
- Dynamic simulation model
- IPS program transition planned – ship impact/cost studies underway
- LABEVAL (FY04)

PHASE III:

- At-Sea demonstration (FY05)

625 kW MODULE INTERNAL ARRANGEMENT

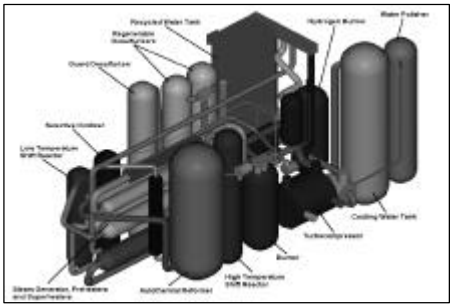


FuelCell Energy

SD1607

Navy Shipboard Fuel Cell Program

Ship Service Fuel Cell Program Demonstration



McDermott Technology

500kW SSFC Autothermal Reformer (ATR) based NATO F76 Diesel Integrated Fuel Processor (IFP)

PHASE I: Completed ($ 4.5 M) FY00

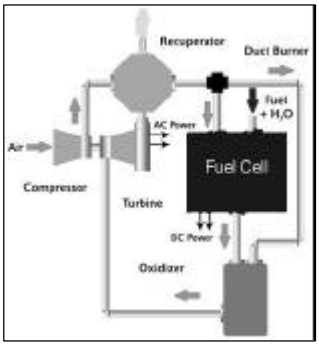
- 2.5 MW *PEM SSFC* Conceptual Design
- Sub-scale risk reduction demonstrations
  - Cell salt air tolerance
  - NATO F-76 diesel fuel reforming
  - Fuel contaminant removal and cell sensitivity (sulfur, CO, ammonia, amines)
  - Cell shock and vibration
- Analytical performance model
- Marine/Navy market surveys

PHASE II: (36 month, $16.5M 50% cost shared ONR program.

- Initial $1.8M ONR contract award July 00 to MTI)
- 500kW IFP preliminary design
- 500kW IFP detailed design
- 500kW IFP fabrication
- 500kW IFP factory testing
- Dynamic simulation model

Navy Shipboard Fuel Cell Program

HPFC S&T Development



Solid Oxide Fuel Cell coupled to a gas turbine generator to provide a 70% efficient power source scaleable to 20MW.

- Advanced Fuel Reforming
- Sulfur Tolerance
- HPFC Design & Trade Off
- SOFC/GT Hybrid Modeling
- SOFC Marinization
- Multistage FC

Navy Shipboard Fuel Cell Program

Interagency Working Group

RADM John T. Tozzi
Assistant Commandant for Systems

RADM G. Gaffney, II
Chief of Naval Research

RADM M.T. Coyle
Deputy Commander for Engineering

Mission Statement

- Foster the use of Fuel Cells for ship applications utilizing diesel fuels to fulfill national transportation needs.
- Transfer the technology to the public.
- Actively involve industry in the development efforts.
- Reduce duplicative efforts – coordinate/cooperate on marine fuel cell requirements.
- Demonstrate the effectiveness of focused interagency partnership.

Diana H. Josephson
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Fenton Carey
Associate Administration for Research,Technology & Analysis

Original Signatories to MOU Approved 2 February 1998

Foreign Marine Fuel Cell Interest

- **Canada:** Ballard developing 200 kW methanol/LOX fuel cell for military submarines.
- **Germany:**
  - Siemens Power Generations Group recently delivered 300 kW PEM fuel cell for Class 212 submarines.
  - HDW has tested 2 Ballard 80 kW PEM power plants for submarine service.
- **UK:** UK is interested in jointly developing a 1.5 MW ship service PEM fuel cell.
- **French & Netherlands** Navies are investigating marine fuel cell applications.
- **Japan**: Evaluating fuel cells for marine applications.
- **Italian Navy:** Proposed 1MW MC FC system for surface ship applications.
- **4 NATO Countries** supporting diesel fuel reforming (100 KW) demonstrations.

Summary

- High efficiency fuel cell systems provide the potential for substantial payoff with reduced production of overall emissions in commercial and military applications.
- ONR/NAVSEA program underway to demonstrate Fuel Cell Power Systems for future naval combatants and other craft.
- Navy Shipboard Fuel Cell Program is developing technology to overcome unique Navy technical challenges while leveraging commercial fuel cell advancements.